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# BEHAVIOR OF REINFORCED MASONRY WALL WITH BOUNDARY BEAMS SUBJECTED TO CYCLIC LOADING

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## SUMMARY

Three reinforced masonry (RM) walls with boundary beams were tested with horizontal cyclic loading corresponding to earthquake motions. These specimens were selected from the first story parts of a prototype five story apartment building with parameters of length of wall and existence of transverse wall. It is verified that the transverse wall is effective on the strength and the deformation capacity and that the larger length of wall decrease the deformasion capacity of wall. And total behaviors of assemblages were obtained.

## INTRODUCTION

Tests of RM walls and RM beams were performed in 1984 (Refs.1 and 2) under U.S.-Japan Coordinated Earthquake Research Program on Masonry Buildings. Based on these test results, three walls with boundary beams were tested with horizontal cyclic loading corresponding to earthquake motions. Because the medium-rise RM buildings which will be able to design and construct through the japanese side research are expected to have a little ductile characteristics, flexural yields should occur at the bottom of the wall at the first story and at the both ends of all beams. In this failure mechanism, the important structural elements are walls in the first story and beams in each story. Therefore, the specimens were selected from the first story parts of the prototype five story apartment building with the parameters of length of wall and existence of a transverse wall, and the seismic performance of the specimens were verified.

## OBJECTIVES

Objectives of this test are listed as follows;

1) to know the total behavior of assemblages
2) to know the effect of the length of the wall on the capacity of deflection
3) to know the effect of the transverse wall on the capacities of strength and deflection of the wall
4) to know the effect of RC slab on the strength of the beam

## SPECIMEN AND LOADING METHOD

Each specimen consists of one RM wall and two RM boundary beams, and a RC floor slab. Name of the specimens, dimensions, arrangement of reinforcing bars, and material properties are tabulated in Table 1. Shape of concrete block units used in these specimens is shown in Fig.1. Three specimens, WG1, WGC1, and WGC2, are illustrated in Fig.2. WG1 was 219cm in length of the wall, 201cm in height of the wall from the top face of the base to the bottom of the beams, and 280cm in story height . Boundary beams were 80cm in height, 150cm in length from the side face of the wall to the pin supported point. All vertical reinforcing bars of wall had lap joints in the bottom part of the wall. Length of the lap joints was 40 times as long as the diameter of the reinforcing bars. Spiral reinforcing bars were arranged around the main flexural reinforcing bars in the bottom of the wall and the lower part of the beams facing to the wall. WGC1 had the additional transverse wall at the center of the wall of WG1. The transverse wall was two 1m long walls at the both sides of the wall. WGC2 was the same detailes as WGC1 except the length of the wall was 379 cm.

Setup of the specimen and loading jacks is illustrated in Fig.3. Steel rods with two mechanical pins at both ends were installed between the reaction floor and the outer end of each beam. Horizontal load was applied by two static jacks. Heights of the horizontal loading point were determined to reproduce the same stress condition as that of the prototype five story wall. In cases of WG1 and WGC1, height of the horizontal loading point was 3.4m. The height of the loading point of WGC2 was 4.4m. The axial load was applied by four static jacks to keep the constant axial stress of 20kg/cm$^2$ at the bottom of the wall.

## TEST RESULTS

Relationships between the shear stress and the story drift angle obtained from the tests are shown in Fig.4 with processes of crack development and events during the test. The shear stress is a value of the applied horizontal load divided by the cross sectional area of the wall without that of the transverse wall. The story drift angle (R) is a value of the horizontal deflection at the floor slab devided by the story height.

Crack patterns Fig.5 shows the final crack patterns. In all specimens, there were no cracks to be found within the shear force corresponding to the base shear coefficient of 0.2 that is the allowable stress design level. The development of crack in each specimen was as follows ;

1)WG1 : Flexural cracks at the bottom of the wall and the lower part of the beam ends facing to the wall occurred along the joint mortar at R=1/4000radian. Flexural shear cracks started from a half story height of the wall at R=1/850radian, and those from the upper part of the wall occurred in accordance with increase of the story drift angle until 1/200radian. At R=1/200radian, compressive cracks occured at the bottom of the wall. After R=1/200radian, the crack pattern did not change largely, but small cracks appeared around the major cracks. Width of flexural cracks of the wall at the both ends of the lap joints became large. However, width of the flexural cracks within the range of the lap joints did not become so large because the amount of reinforcing bars increased at the lap joints. By flexural stress of the beam, vertical cracks occurred in the joint panel to the extent of 20cm from the side face of the wall. And it is considered that the cracks indicate the end of the rigid zone of the joint panel. Finally compressive failure occurred at the bottom of the wall and the lower part of the beams at R=1/100radian. Crack did not appear in the center part of joint panel.

2)WGC1: Process of the crack development was similar to that of WG1. However the location to where flexural cracks concentrated at the bottom of the wall was nearer from the center of the wall than that of WG1. This phenomenon is considered to be caused by the increase of compressive stress at the compression toe of the wall because the vertical reinforcing bars in the transverse wall worked in tension side. Cracks occured horizontally at the bottom of the transverse wall at R=1/1000radian.

3)WGC2: Flexural cracks at the bottom of the wall and the lower part of the beam ends facing to the wall occurred along the joint mortar at R=1/7000radian and R=1/3000radian, respectively. Flexural shear cracks started from a half story height of the wall at R=1/1200radian, and flexural cracks in the wall occurred in the full height of the wall by R=1/400radian. Cracks which occurred in the wall at the second story penetrated the slab to the joint panel at R=1/300radian. These cracks occurred because the height of the inflection point of moment was higher than that of WG1 and WGC1. At R=1/450radian, compressive cracks occured at the bottom of the wall. Finally compressive failure occurred at the bottom of the wall and the lower part of the beams at R=1/150radian.

Strain of Reinforcing Bars Flexural reinforcing bars in the bottom of the walls started to yield at R=1/800radian for WGC2 and 1/400radian for WG1 and WGC1. The lower flexural reinforcing bars in the beams yielded at R=1/400radian and the upper flexural reinforcing bars yielded at R=1/200radian. So the walls and the beams are considered to have yielded in flexure. Vertical reinforcing bars in the transverse walls and the slab reinforcements in the loading direction yielded before the specimens reached their maximum strength. So it is considered that the full width of the transverse walls and the slabs so far as in this test are effective on flexural strength.

Strength Fig.6 shows the skeleton curves of relationships between the shear stress and the story drift angle with calculated results. In the calculation of the maximum strength, it was assumed that the wall and the beams are failed in flexure and that all width of the transverse wall and the slabs are effective on the flexural strength of the wall and the beams respectively. The ratio of the maximum strength obtained from the test to the calculated strength is 1.21 for WG1 and 1.06 for WGC1 and WGC2. This difference between the ratios is concidered to be caused by the accuracy of the evaluation of the effect of the transverse wall for the flexural strength of walls. The ratio of the flexural strength of the wall obtained from the test to that from calculation is 1.16 for WG1, 0.98 for WGC1, and 1.03 for WGC2. Same ratio of the distance between the centers of compressive and tensile stress to the length of the wall was used in the calculation of the flexural strength of each specimen. However, in the test, the ratios of WGC1 and WGC2 were smaller than that of WG1 because the neutral axes of WGC1 and WGC2 moved to the inner part of the wall than the assumed place in the calculation by the effect of reinforcing bars in the transverse wall. Therefore, the ratio of tested strength to calculated strength was smaller for the specimens with the transverse wall than that of the specimen without the transverse wall. It is considered that the flexural strength should be calculated with considering the effect of the transverse wall on the neutral axis.

Deflection Capacity WG1 yielded at around R=1/400radian when the yield of the flexural reinforcing bars in the wall and the compressive cracks at the bottom of the wall occurred. WG1 reached the maximum strength at R=1/100radian. After that the deterioration of strength was large.

WGC1 showed almost the same characteristics of deflection as WG1, but the deterioration of the strength after R=1/100radian was smaller than that of WG1. It is considered that the deflection capacity of WGC1 increased bcause of the effect of the transverse wall.

WGC2 yielded around R=1/800radian and reached the maximum strength at R=1/200radian. The deterioration of strength in the positive loading after the maximum strength was large, however, the deterioration of strength in the negative loading after the maximum strength was not so large. This is caused by incompleteness of concrete grouting around the spiral reinforcement in the compressive side bottom of the wall in the positive loading.

## CONCLUSIONS

Conclusions obtained from the test are as follows;

1) The wall of which length was longer, WGC2, showed smaller deflection capacity than WG1 and WGC1.
2) The full width of the transverse wall which is 1m wide on each side of the wall was effective on the flexural strength of the wall. And the wall with the transverse wall showed a better deflection capacity than the wall without the transverse wall.
4) The flexural strength should be calculated with considering the effect of the transverse wall on the neutral axis.
5) The full width of the slab which is 1m wide on each side of the beam was effective on the flexural strength of the beam.
6) A deterioration of strength became large after R=1/100radian. However, the specimens had enough deformation capacity for the prototype RM building.
7) As the moment inflection point of the wall became higher, flexural shear cracks occurred to higher part of the wall and more cracks appeared in the joint panel.
8) Lap joints did not affect on the strength and the deflection capacity.
9) Spiral reinforcement was effective on confining the concrete at compressive zone.

## ACKNOWLEDGMENT

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## REFERENCES

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Table 1 List of Test Specimens and Material Properties

| Specimen | | WG1 | WGC1 | WGC2 |
|---|---|---|---|---|
| Story Height(cm) | | 280.5 | | |
| Loading Height(cm) | | 340 | | 440 |
| Wall | Width(cm) | 219 | | 379 |
| | Thickness(cm) | 19 | | |
| | Height(cm) | 201 | | |
| | Main V.Re-bar | 2-D19 | | |
| | Sub V.Re-bar | 1-D16@400 | | |
| | Shear H.Re-bar | 1-D13@200 | | |
| | Spiral Re-bar | 6φ,Dia.100,pitch40 | | |
| Beam | Height(cm) | 79.5 | | |
| | Thickness(cm) | 19 | | |
| | Length(cm) | 125+25(Pin Support) | | |
| | Main H.Re-bar | 2-D19 | | |
| | Sub H.Re-bar | 1-D16 | | |
| | Shear V.Re-bar | 1-D13@200 | | |
| | Spiral Re-bar | 6φ,Dia.70,pitch67 | | |
| Trans. Wall | Width(cm) | — | 100+100 | |
| | Thickness(cm) | — | 19 | |
| | Sub V.Re-bar | — | 1-D16@400 | |
| | Shear H.Re-bar | — | 1-D13@200 | |
| Slab | Width(cm) | 219 | | |
| | Thickness(cm) | 15 | | |
| | Longi. Re-bar | 2-D10@400 | | |
| | Trans. Re-bar | 2-D10@200,@400 | | |
| Prism Compressive Strength($kg/cm^2$) | | 186 | | 164 |
| Compressive Strength of Concrete($kg/cm^2$) | | 267 | 229 | |
| Yield Stress of Re-bar ($kg/cm^2$) | D10(SD30) | 3653 | | |
| | D13(SD30) | 3603 | | |
| | D16(SD35) | 3840 | | |
| | D19(SD35) | 3993 | | |
| | 6φ | 2967 | | |

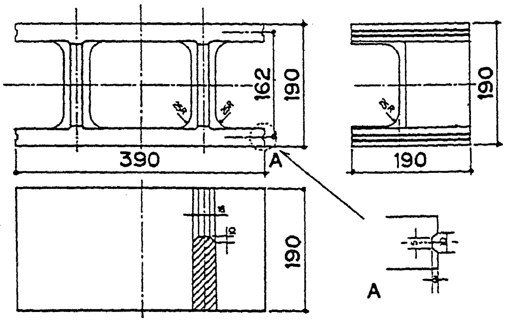
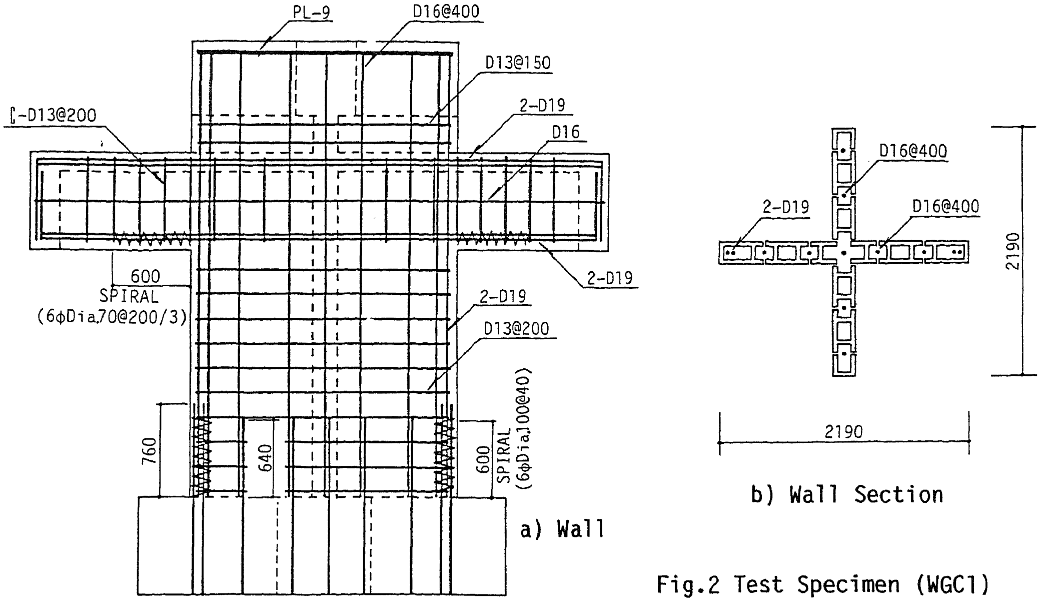


Fig.1 Shape of Concrete Block Unit



a) Wall

b) Wall Section

Fig.2 Test Specimen (WGC1)

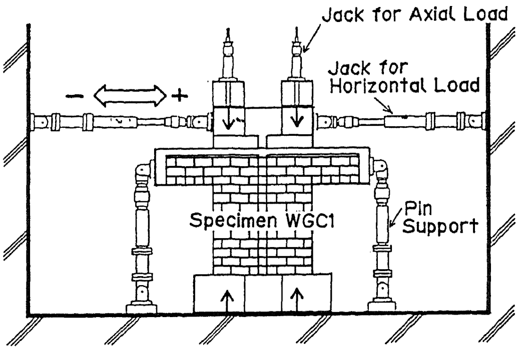
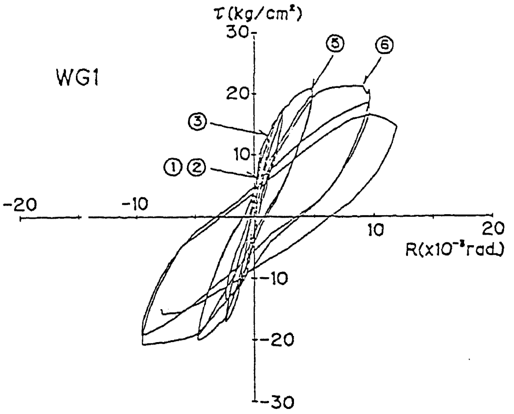
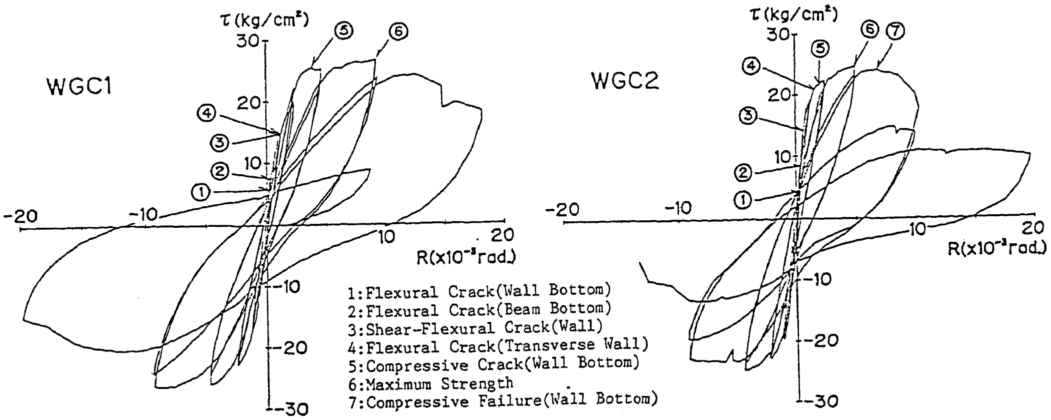


Fig.3 Loading System





1:Flexural Crack(Wall Bottom)
2:Flexural Crack(Beam Bottom)
3:Shear-Flexural Crack(Wall)
4:Flexural Crack(Transverse Wall)
5:Compressive Crack(Wall Bottom)
6:Maximum Strength
7:Compressive Failure(Wall Bottom)

Fig.4 Shear Stress vs. Story Drift Angle Relationships

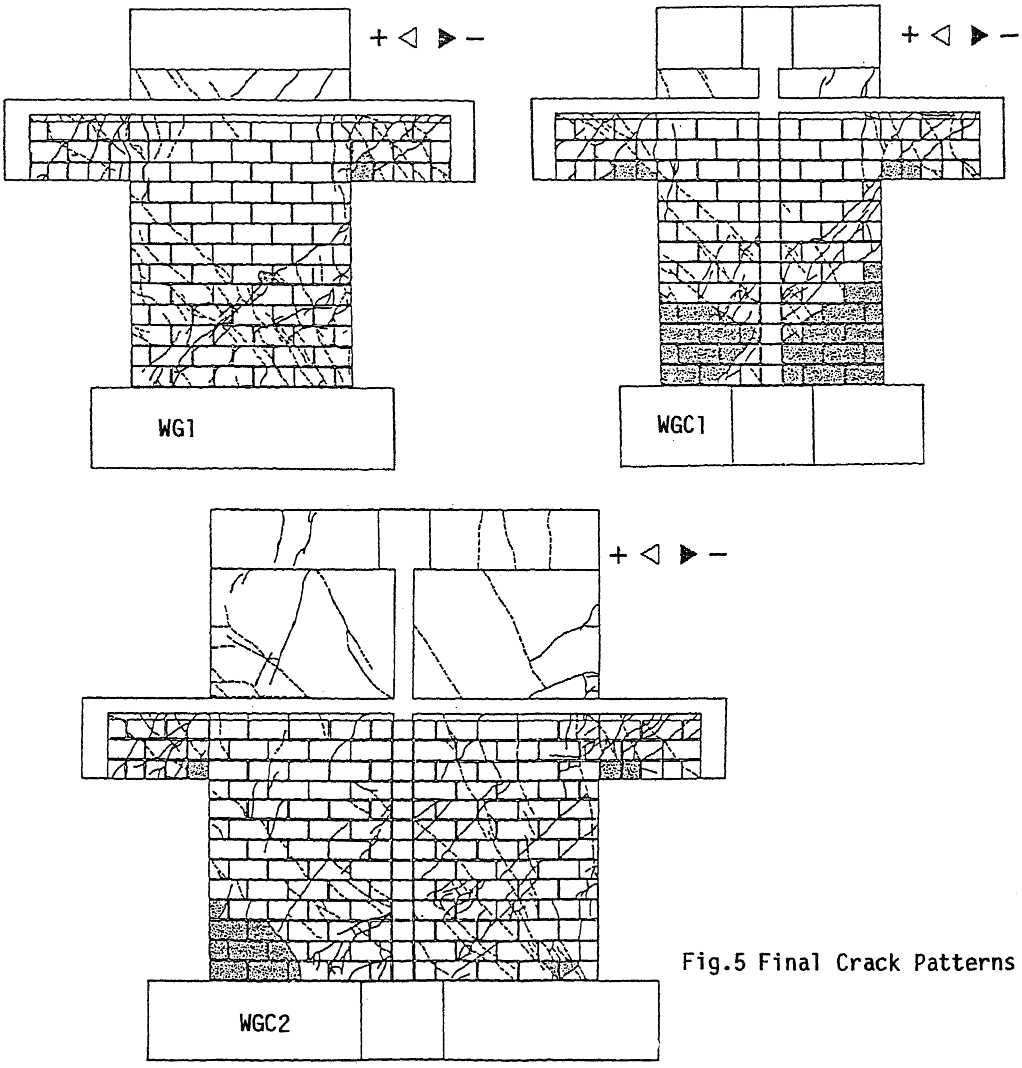


Fig.5 Final Crack Patterns

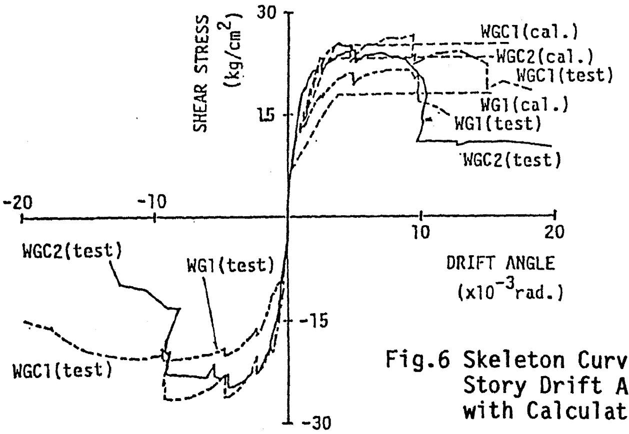


Fig.6 Skeleton Curves of Shear Stress vs. Story Drift Angle Relationships with Calculated Results